Original Research Article||

Evaluation of vermicompost on growth, yield and yield components of potato (*Solanum tuberosum* L.) in Debub Ari Woreda, Southwestern Ethiopia

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Abstract

The low levels of organic materials applied to the soil and the complete removal of the biomass from the field during harvesting, causes soil fertility depletion and limits crop production in Ethiopia. This experiment was conducted to evaluate the effect vermicompost on the productivity of potatoes in Debub Ari Woreda, southwestern Ethiopia. The experiment was conducted in the 2019 and 2020, where the combined data of the two production years were used for evaluating treatment effects. Control, (69 N+30 P) kg ha^{-1}, 3 t ha^{-1} vermicompost, 4.5 t ha^{-1} vermicompost and (34.5N+15P) kg ha^{-1} with 1.5 tha^{-1} vermicompost treatments were used as experiment levels that were laid out in randomized complete block design in three replication with the spacing of 30 and 75 cm between plants and rows, respectively. The full dose of vermicompost and inorganic fertilizers were applied at planting time. The result was revealed that application of 69 kg ha^{-1} N+30 kg ha^{-1} P resulted in the highest total (47.18 t ha^{-1}) and marketable (40.56 t ha^{-1}) tuber yields, which were statistically at par with respect to application of 3 and 4.5 t ha^{-1} vermicompost, while the lowest total (29.99 t ha^{-1}) and marketable (26.46 t ha^{-1}) tuber yield were recorded from the nil. However, pH and total nitrogen of the soil was influenced by the application of 3 and 4.5 t ha^{-1} levels of vermicompost. Application of 3 t ha^{-1} of vermicompost resulted in the highest marginal return of 4854% and improved soil health and fertility over the application of inorganic fertilizer alone and control. Therefore, the application of 3 t ha^{-1} vermicompost was recommended for the study area and others with similar agro-ecologies. Further investigations should be done on the rate, tuber nutritional value and quality, as well as over locations.

Key words: Productivity, Soil fertility, Soil properties, Vermicompost

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INTRODUCTION

Potato is one of mankind's most valuable food crops. Its relatively high in carbohydrate and low in fat contents, making it an excellent energy source for human consumption. It is said to be one of the most efficient crops in converting natural resources, labor, and capital into high-quality food with wide consumer acceptance (MOANR, 2016). Despite its amenability to wide range of agroecology and its nutritional importance for human, potato production in Ethiopia is very low (14.18 t ha^{-1}) (CSA, 2019) compared to the its potential of 47 t ha^{-1} (MOANR, 2009).

Depletion of soil fertility, poor agronomic practices as well as diseases and pests are among the main production problems that account for the low national yield compared to neighboring countries such as Kenya and Uganda (Gildemacher *et al*., 2009). Moreover, depletion of soil organic matter, macro- and micronutrients, coupled with poor soil health and crop nutrient imbalances are among the primary biophysical limitations that decrease agricultural production in Ethiopia (Zeleke *et al*., 2010). Most cultivated soils of Ethiopia are poor in their organic matter contents due to the low levels of organic materials applied to the soil and complete removal of the biomass from the field (Gebreselassie, 2002). Moreover, the increased cost of mineral fertilizers from time-to-time vis-a-vis price of potato product on the market and their long-term effects on soil chemical properties is among the constraints that hinder improvement of potato production (Negassa *et al*., 2001, Azizi *et al*., 2015).

Appropriate use of organic amendments like application of vermicompost promote humification, increased microbial activity, and enzyme production, which, in turn, increases the aggregate stability of soil particles, resulting in better aeration (Tisdall and

Oades, 1982; Haynes and Swift, 1990 and Perucci, 1990). Soil microbial biomass and enzyme activity are important indicators of soil improvement as a result of the addition of organic matter such as vermicompost (Perucci, 1990). Vermicompost also contains plant growth promoters, such as auxins and cytokinins (Krishnamoorthy and Vajranabhaiah, 1986).

Application of vermicompost for vegetable crop production especially root crops like potato shows promising potential for improving crop productivity, soil health retainment and soil physicochemical improvement (Ansari and Sukhraj, 2010; Piya *et al*., 2018). Additionally, application of vermicompost for vegetable production can solve the problem of disposal of wastes and lack of soil organic matter (Alam *et al*., 2007). It is proving to be a highly nutritive 'organic fertilizer' and more powerful 'growth promoter' and a 'protective' farm input (improving the physical, chemical and biological properties of soil and restoring its natural fertility) against the 'destructive' chemical fertilizers which has destroyed the soil properties and decreased its natural fertility over the years (Sinha *et al*., 2009). It supplies balanced nutrients to plant roots and stimulates growth; increases the organic matter content of the soil including the 'humic substances' that affect the nutrient accumulation and promote root growth (Siminis *et al*., 1998; Canellas *et al*., 2002). Vermicompost improves the total physical and chemical properties of the soil and also add useful micro-organisms to the soil and provide food for the existing soil micro-organisms and thus increase their biological properties and capacity of self-renewal of soil fertility (Shiralipour *et al*., 1992; Ouédraogo *et al*., 2001). Application of 8 t ha^{-1} vermicompost increases the yield of potato by 53.1% over control along with increased quantity, quality, and presentation of products (Akbasova *et al*., 2015). The current research was designed to evaluate the effect of vermicompost on the production of potatoes and its effect on soil physical and chemical properties in Debub Ari Woreda, Southwestern Ethiopia.

MATERIALS AND METHODS

Description of the study area

A field experiment was conducted in the 2019 and 2020 in Debub Ari Woreda, Southwestern Ethiopia. The experimental site was geographically located in the ranges of 05°07.4'-05°07.8' N latitude and 36°40.1'- 36°40.9' E longitude with an elevation of 1917-1919 meters above sea level. It is found in the northeastern direction of Jinka town**.** The study area has a bi-modal rainfall pattern with a shorter rainy season from March-May and the longest rainy season from August- November. The experiment was conducted in one of the rain-fed areas of the zone where the experimental crop (potato) was planted during the long rainy months. The average total annual rainfall during the experimental years ranged from 1342 to 1381 mm (Southern agro-meteorological observatory station).

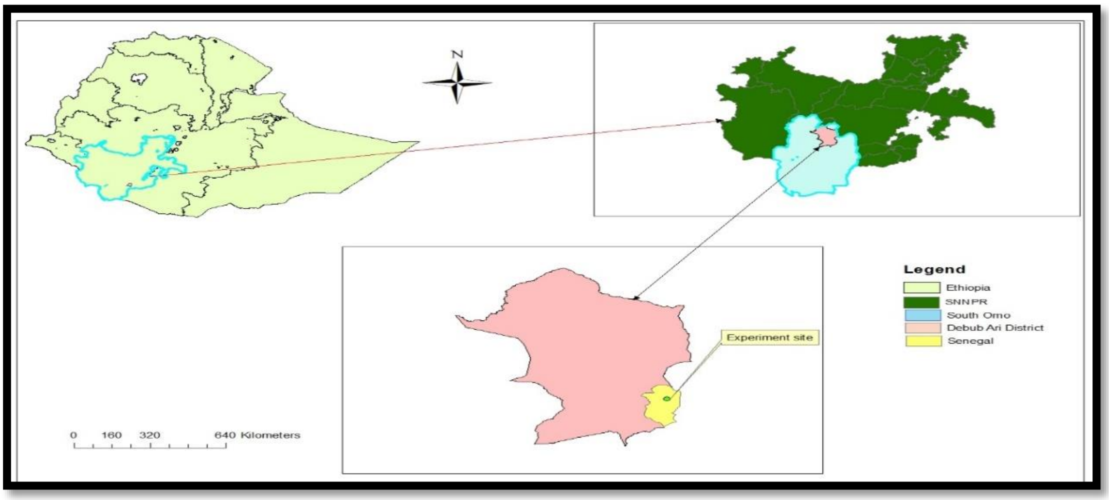

Figure 1. Map of the study area

Experimental design and treatments

The experiment was laid out in a Randomized Completely Block Design (RCBD) with three replications on a plot of 3.9 by 4.5 meters and spacing of 30 and 75 cm between plants and rows, respectively. Improved potato variety, Belete was used for the experiment. Five treatment levels namely:

T1 Control (No fertilizer); T2 69 kg ha^{-1} N and 30 kg ha^{-1} P; T3 3 t ha^{-1} vermicompost; T4 4.5 t ha^{-1} vermicompost; T5 Half of recommended NP (34.5 kg ha^{-1} N and 15 kg ha^{-1} P) with 1.5 t ha^{-1} vermicompost

Urea and Triple Super Phosphate fertilizers were used as a source of nitrogen and phosphorus, respectively. Vermicompost used in the experiment was prepared by using farmyard manure, paper, newspaper, card board, litter fall as raw materials for feeding earthworm (*Eisenia foetida*) at Jinka Agricultural Research Center; which was applied at the time of planting.

Data collection and analysis

Data were recorded for plant height, number of tubers per hill, tuber diameter, marketable tuber yield, unmarketable tuber yield, and total tuber yield of combined data of two years based on homogeneity test.

Composite soil samples were prepared from soil samples collected from fifteen spots from the experimental area at depth of 0-20 cm in zigzag movement before planting. Soil sample from each plot was collected after harvesting and prepared for laboratory analysis in treatment base. The collected soil samples before planting and after harvesting were analyzed for texture, pH, organic carbon, total nitrogen, and available phosphorus at the soil laboratory of Jinka Agricultural Research Center. All the collected data were analyzed using the SAS Statistical Software Version 9.1. Effects were considered significant in all statistical calculations if the p-value was < 0.05. Means were separated using the Least Significant Difference (LSD) test.

Economic analysis

The economic evaluation comprising of partial budget analysis with dominance and marginal analysis was carried out. To estimate economic parameters, the marketable tuber yield was valued based on the average market price collected from the local markets during two consecutive years of production. The average cost of urea and TSP fertilizers was 15.51 and 15.85 birr per kilogram respectively. A wage rate of 50 birr a man per day; and 13 birr per kilogram of marketable tuber value of potato were considered. The dominance analysis was also done to select potentially profitable treatments. It was carried out by first listing the treatments in order of increasing costs. Any treatment that has net benefits less than or equal to those of treatment with lower costs that vary is dominated. The selected treatments by using this technique were referred to as un-dominated treatments. For each pair of ranked un-dominated treatments, a percentage marginal rate of return (% MRR) was calculated. The %MRR between any pair of un-dominated treatments denoted the return per unit of investment in crop management practices which was expressed in percentage. The marginal rate of return was calculated as the ratio of differences between net benefits of successive treatments to the difference between total variable costs of successive treatments. (CIMMYT, 1988). For a treatment to be considered a worthwhile option to farmers, the marginal rate of return needed to be at least 100%. Some of the concepts used in the partial budget analysis are gross field benefit (GFB), total variable cost (TVC), and net benefit (NB) as summarized below:Gross margin ($ETBha^{-1}$) = Total revenue ($ETBha^{-1}$) – Total variable cost ($ETBha^{-1}$)

NR Net return ($ETBha^{-1}$) = Gross margin ($ETBha^{-1}$) – Total fixed cost ($ETBha^{-1}$)

Total cost of production ($ETBha^{-1}$) = Total variable cost ($ETBha^{-1}$) + Total fixed cost ($ETBha^{-1}$)

Benefit-cost ratio = Net Return/Total Cost of Production (CIMMYT, 1988)

RESULTS AND DISCUSSION

Soil and vermicompost analysis

Results of an analysis of soil samples for texture, pH, organic carbon, total nitrogen, and available phosphorus before planting are presented in Table 1. The soil of the experimental site has a proportion of 16% sand, 29% silt, and 16% clay; and it was classified as clay according to the soil textural triangle. The pH of the experimental site (1:2.5 ratio of soil to water suspension) was 5.69, which implied that the soil of the study site was moderately acidic according to Tekalign *et al.*, (1991) and Marx *et al.*, (1999). The organic carbon of the soil was done by Walkely Blacky methods (Black 1965) and its value was 3.09%, which was rated as high according to Tekalign *et al.*, (1991). The result of soil analysis indicated that the soil has total nitrogen of 0.24% by Keljdal digestion and distillation followed by titration method; which implied that the soil of the experimental site has a medium level of total nitrogen according to Bruce and Rayment, (1982) and Tekalign *et al.*, (1991). The experimental soil has available phosphorus of 22.69 ppm analysed by Olsen methods which were effective for both alkaline and acidic soil categories and extracted by 1M $NaHCO_3$, which was a high level according to Olsen *et al*., (1954) and Marx *et al.*, (1999).

Table 1. Some Physicochemical properties of the soil before the experiment

Physicochemical properties	Composition	
	Soil	Vermicompost
Sand (%)	16	
Silt (%)	29	
Clay (%)	16	
Textural class	Clay	
pH (H_2O) (1:2.5)	5.69	7.13
OC (%)	3.0875	4.39
TN (%)	0.238	0.966
Ava. P (ppm)	22.69	133.84
Ava. S (ppm)		17.15
Ava. B (ppm)		1.198

Where TN= Total Nitrogen; OC= Organic Carbon, Ava. P= Available Phosphorus, Ava. S= Available Sulphur, Ava. B= Available Boron

An addition of vermicompost significantly improved the soil pH, organic carbon, available nitrogen, and phosphorus, during 2019-2020 in the study site (Table 2). An increase in pH from 5.69 of initial soil to 6.35 was observed in the plot fertilized with 4.5 t ha^{-1} VC, whereas, the lowest pH was observed from the inorganic treatment. Organic carbon of the soil of the experimental area did not show a significant difference along with application of treatments, which is likely due to the initially high level of organic carbon in the experimental area.

There was an increase of 0.032% in total nitrogen in response to application of 4.5 t ha^{-1} vermicompost which was statistically in parity with the application of 3 t ha^{-1} vermicompost and 69 kg ha^{-1} N and 30 kg ha^{-1} P treatments. Reduction of total nitrogen was observed on unfertilized treatment (control) and the integrated application of organic and inorganic treatments. Application of vermicompost did not affects available phosphorus of the experimental area, which might be due to the high level of initial phosphorus in the soil of the experimental area (Table 2).

Plant height

Analysis of variance revealed that the plant height of potato has been influenced by different treatments. The highest plant height of 82.67 cm was recorded from the application of 1.5 t ha^{-1} with half of recommended NP fertilizer, which was in statistical parity with the rest of the treatments except the one receiving 3 t ha^{-1}, whereas the lowest plant height of potato was obtained from 3 t ha^{-1} which was in statistical parity with the rest of the treatments except the application of 1.5 t ha^{-1} with half of recommended NP fertilizers (Table 4). Likewise, Alam *et al*., (2007) reported that the highest plant height was found with the application of vermicompost at a rate of 10 t ha^{-1} + 50% NPKS fertilizers. Plant height of potato was significantly influenced by application of 3 t ha^{-1}, 4.5 t ha^{-1}, 69 kg ha^{-1} N + 30 kg ha^{-1} P, 34.5 kg ha^{-1}N and 15 kg ha^{-1}P with 1.5 t ha^{-1} vermicompost treatment was in agreement with application of organic, inorganic and bio fertilizers in affecting plant height of potato (Mohammed *et al*., 2018; Subhranath *et al*., 2020).

Table 2. Some physical and chemical properties of the soil after the experiment

Treatments	Soil properties			
	pH (H_2O) (1:2.5)	OC (%)	TN (%)	Ava. P (ppm)
Control	6.22^{ab}	3.05	0.15^{b}	31.98
69 kg ha^{-1} N and 30 kg ha^{-1} P	6.06^{b}	2.76	0.25^{a}	37.48
3 t ha^{-1} VC	6.11^{ab}	2.98	0.24^{a}	33.13
4.5 t ha^{-1} VC	6.35^{a}	2.93	0.27^{a}	33.41
34.5kgha^{-1}N and 15kgha^{-1}P +1.5 t ha^{-1} VC	6.09^{b}	3.41	0.15^{b}	35.69
$LSD_{0.05}$	0.2468	NS	0.0345	NS
CV	2.13	14.10	8.65	17.39

Means with the same letter show statistically not a significant difference at $LSD_{0.05}$; VC= Vermicompost; t ha^{-1}=ton per hectare; N= Nitrogen; TN= Total Nitrogen; OC= Organic Carbon and Ava. P= Available Phosphorus

Table 3. Growth, yield, and yield traits of potato as influenced by application of vermicompost

Treatments	Plant height (cm)	Tuber $hill^{-1}$	Tuber Diameter (cm)	Marketable yield (t ha^{-1})	Unmarketable yield (t ha^{-1})	Total yield (t ha^{-1})
Control	80.67^{ab}	10.53	14.67^{b}	26.46^{b}	3.53	29.99^{b}
69 kg ha^{-1} N and 30 kg ha^{-1} P	82.00^{ab}	12.87	15.67^{b}	40.56^{a}	6.61	47.18^{a}
3 t ha^{-1}VC	76.33^{b}	12.27	17.17^{a}	36.59^{a}	3.97	40.56^{a}
4.5 t ha^{-1} VC	77.67^{ab}	9.47	17.00^{a}	37.04^{a}	4.85	41.89^{a}
34.5kgha^{-1}N and 15kgha^{-1}P + 1.5 t ha^{-1} VC	82.67^{a}	7.93	17.17^{a}	34.39^{a}	5.91	40.29^{a}
LSD	5.76	NS	1.18	6.37	NS	7.73
CV	3.83	29.78	3.83	9.67	39.54	10.27

Means with the same letter show a statistically not a significant difference at $LSD_{0.05}$; Recomm. NP= 69 kg ha^{-1} N and 30 kg ha^{-1} P; VC=vermicompost

Number of tubers per hill

The treatments did not significantly influence the number of tubers per hill of potato (Table 3). The number of tubers per hill of potato was not affected by treatment applications, which agreed with the earlier report (Fahrurrozi et al., 2019). Likewise, Subhranath et al., (2020) indicated that application of integrated nutrient management did not have significant effects on the numbers of tubers per plant.

Tuber diameter

The tuber diameter of potato has been influenced by the different treatments (Table 3). The highest tuber diameter of 17.17 cm was obtained from the application of 3 t ha^{-1} and 1.5 t ha^{-1} compost combined with half of recommended NP fertilizer, while the lowest tuber diameter of 14.67 cm was recorded from the nil one which was statistically at par with recommended NP treatments (Table 3). Tuber diameter of potato has been significantly affected by treatment applications, which agreed with previous report where tuber diameter of potato with increasing vermicompost rate was reported, which might be due to sufficient nutrient supplied by vermicompost for tuber development together with its effect on decreasing soil compaction (Fahrurrozi *et al*., 2019). This result was also in agreement with Garczyńska *et al*. (2020), where using vermicompost for the cultivation of sweet potatoes had a positive effect on the size and structure of tuber/root yield.

Marketable tuber yield

The marketable tuber yield of potatoes was significantly affected by the different treatments, where the highest value (40.56 t ha^{-1}) was obtained from the application of 69 kg ha^{-1} N and 30 kg ha^{-1} P, although it was statistically at par with the rest of the treatment levels except the control. The lowest marketable tuber yield (26.46 t ha^{-1}) on the other hand was recorded from the nil (control) treatment. An increasing trend of marketable tuber yield of potato with the application of vermicompost and recommended NP was observed (Table 3). Similarly, Amin, (2018) reported that the marketable tuber yield of potato was influenced by application of organic and inorganic fertilizers. The trends of marketable tuber yield of potato observed in this research was in line with that reported other literatures (Yeng *et al*., 2012; Mohammed *et al*., 2018).

Unmarketable tuber yield

The unmarketable tuber yield of potatoes was not significantly influenced by treatments (Table 3). Similarly, Mohammed *et al*., (2018) reported that applications of organic fertilizer and inorganic fertilizers separately or in combinations, as well as integrated application of organic and inorganic fertilizers did not affect the unmarketable tuber yield of potato. Likewise, the application of cattle manure and also inorganic fertilizers did not influence the unmarketable tuber yield of potatoes (Amin, 2018).

Total tuber yield

The total tuber yield of potato was significantly influenced by different fertilizer applications (Table 3). The highest total tuber yield of 47.18 t ha^{-1} was obtained in response to the treatment containing application of 69 kg ha^{-1} N and 30 kg ha^{-1} P which was statistically higher than only the control, which gave lowest yield (29.99 t ha^{-1}) (Table 3). The result from the current work also agrees with reports of other study (Alam *et al*., 2007; Mohammed *et al*., 2018). Likewise, the application of vermicompost at the rate of 8 t ha^{-1} gave a 34.69% increment in the total tuber yield of potato over the control (Bongkyon, 2004; Akbasova *et al*., 2015).

Economic Analysis

Partial budget analysis of vermicompost application for potato production experiment in Debub Ari district revealed that the highest net return of 467,456 ETB ha^{-1} was obtained in response to application of 69 kg ha^{-1}N and 30 kg ha^{-1} P which showed 33.77% higher net return over the control (309582 ETB ha^{-1}); followed by 4.5 t ha^{-1} vermicompost treatment with net return of 429780 ETB ha^{-1}. The lowest net return of 309582 ETB ha^{-1} was obtained from the absolute control treatment (Table 4).

Dominance analysis revealed that 3 t ha^{-1}, 4.5 t ha^{-1} and 69 kg ha^{-1} N + 30 kg ha^{-1} P treatments were un dominated, while 34.5 kg ha^{-1}N and 15 kg ha^{-1}P with 1.5 t ha^{-1} treatment was dominated (Table 5). This indicated that an increase in the total cost of 3 t ha^{-1}, 4.5 t ha^{-1} and 69 kg ha^{-1} N + 30 kg ha^{-1} P treatments increases the net benefit proportionally; which implies that benefits of these treatments were greater than the lower total costs. The highest net benefit was obtained from the application of 69 kg ha^{-1}N + 30 kg ha^{-1} P with a marginal rate of return of 1074%, but the highest marginal rate of return of 4854% was obtained in response to the application of 3 t ha^{-1} (Table 5). Therefore, 3 t ha^{-1}, 69 kg ha^{-1} N + 30 kg ha^{-1} P, and 4.5 t ha^{-1} vermicompost with %MRR of 4854%, 1074%, and 340%, respectively were accepted as a worthwhile option to farmers according to CIMMYT (1988) as %MRR value was above 100%.

Table 4. Partial budget analysis, the effect of vermicompost on potato production experiment in Debub Ari Woreda

Treatments	AVMY ($t\ ha^{-1}$)	10% AJY ($t\ ha^{-1}$)	TR (ETB ha^{-1})	TVC (ETB ha^{-1})	NB (ETB ha^{-1})
Control	26.46	23.814	309582	0	309582
69 kg ha^{-1} N and 30 kg ha^{-1} P	40.56	36.504	474552	7096	467456
3 t ha^{-1} VC	36.59	32.931	428103	2392	425711
4.5 t ha^{-1} VC	37.04	33.336	433368	3589	429780
34.5 kgha^{-1} N and 15 kgha^{-1} P + 1.5 t ha^{-1} VC	34.39	30.951	402363	3548	398815

Where AVMY = average marketable yield; 10%AJY = Yield adjusted 10% downward; TR = total revenue; ETB= Ethiopian Birr; TVC = total variable cost; NB = net benefit; and VC= Vermicompost

Table 5. Dominance and Marginal (%MRR) analysis, vermicompost effect on potato production experiment in Debub Ari district

Treatments	Variables				
	10%AJY ($t\ ha^{-1}$)	TVC (ETBha^{-1})	NB (ETBha^{-1})	DA	MRR (%)
Control	23.81	0	309582	-	-
3 t ha^{-1} VC	32.93	2392	425711	ND	4854
34.5 kg ha^{-1} N and 15 kg ha^{-1} P + 1.5 t ha^{-1} VC	30.95	3548	398815	D	-
4.5 t ha^{-1} VC	33.34	3589	429780	ND	340
69 kg ha^{-1} N and 30 kg ha^{-1} P	36.50	7096	467456	ND	1074

TVC = total variable cost; ETB= Ethiopian Birr; NB = net benefit; and VC= Vermicompost; MRR (%) = Marginal Rate of Return in percent; DA = dominance analysis; 10%Adj. Yield = Marketable tuber Yield Adjusted to 10% downward

CONCLUSIONS

Potato has responded well to the application of vermicompost in 3 t ha^{-1} and 4.5 t ha^{-1}, 69 kg ha^{-1}N + 30 kg ha^{-1} P and integrated use of vermicompost with nitrogen and phosphorus from inorganic sources than the control treatment which was producing potato without applying organic and inorganic fertilizers. Moreover, based on partial budget analysis, a higher net benefit was recorded in response to the application of 69 kg ha^{-1}N+30 kgha^{-1}P. Application of 69 kgha^{-1}N+30 kgha^{-1}P, 4.5 t ha^{-1} and 3 t ha^{-1}gave 33.77%, 27.97% and 27.28% increment in net return over absolute control. However, the soil health and soil fertility improvement were more affected by the application of 4.5 t ha^{-1} and 3 t ha^{-1}vermicompost. Application of 3 t ha^{-1} resulted in the highest marginal rate of return and also improves soil health by enhancing soil pH and soil total nitrogen in the same way with the application of 4.5 t ha^{-1}. Therefore, we recommend the application of 3 t ha^{-1} vermicompost for the study area and other areas with similar agro-ecologies. We also advise farmers and investors to apply 4.5 t ha^{-1} vermicompost for improving potato production and soil health and fertility as a second option. Further investigation should be done on vermicompost rate evaluation and its effect on more physical and chemical properties of soil, tuber nutritional value over multiple locations.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article.

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